Acta Chemica Scandinavica B 35 (1981) 163–168

Dioxolanylium Ions Derived from Carbohydrates. VI. Rearrangement of Derivatives of α- and β-Galactopyranosides and Their Reaction with Nucleophiles

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The position of the equilibrium *2*⇄*3* for a number of 2-phenyl-1,3-dioxolanylium ions, fused to carbohydrates of the *galacto* and *gulo* configuration, has been measured in acetonitrile solution. The anomeric configuration was found to influence both the position of the equilibrium between the benzoxonium ions and the outcome of the *trans*--opening of the benzoxonium ions with bromide ion.

The generation of dioxolanylium ions derived from pentosides by hydride abstraction from the corresponding benzylidene compounds with triphenylmethyl fluoroborate has been described previously.[1-3] This investigation has now been extended to the more complex hexopyranoside system, and the present paper describes benzoxonium ions derived from galactopyranosides, and their reaction with nucleophiles. The choice of hexopyranosides as substrates allows a study of the effect of the anomeric configuration while maintaining the conformation of the pyranose ring. At the same time the effect of conformation on the benzoxonium ion equilibrium and the nucleophilic substitution with bromide ion can be studied by comparison with the previously investigated[3] 1,6-anhydro-galacto- and gulobenzoxonium ions. The corresponding mannose-altrose system will be discussed in the following paper.

Treatment of methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-β-D-galactopyranoside (*β4a*) with trityl fluoroborate in acetonitrile resulted in formation of the galactobenzoxonium ion *β2a*. Its structure was deduced by comparison of the ^1H and ^{13}C NMR spectra with those of the corresponding 6-*O*-tosylate (*β2b*), which exhibited a well-resolved ^1H NMR spectrum (Table 1), clearly revealing the

Table 1. ^1H NMR spectra of benzoxonium ions in acetonitrile-d_3 solution (270 MHz).

Compound	Chemical shifts (δ-values)								Coupling constants (Hz)						
	H1	H2	H3	H4	H5	H6	H6′	CH_3	J_{12}	J_{23}	J_{34}	J_{45}	J_{56}	$J_{56'}$	$J_{66'}$
α2a	5.20	5.69	6.37	6.29	—	≃4.8	—	3.35	4.5	6.0	8.5	≃2			
α2b	5.16	5.66	6.29	6.11	4.66	4.60	4.49	2.43	4.5	6.5	8.5	2.5	9.0	4.5	11.0
α2c	5.20	5.79	6.48	6.4	—	≃4.8	—	3.43	4.3	5.8	8.0	≃2			
α3c	5.31	6.23	5.88	6.16	4.69	—≃5.3—		3.74 4.01	4.9	7.8	3.2	2.8			
β2a	5.18	5.60	6.36	6.35	5.0	4.9	4.84	3.23	3.0	2.0					
β2b	5.10	5.55	6.32	6.23	4.85	4.64	4.57	3.14 2.43	3.0	2.5	9.5	1.5	5.0	6.0	11.0

0302-4369/81/030163-06$02.50

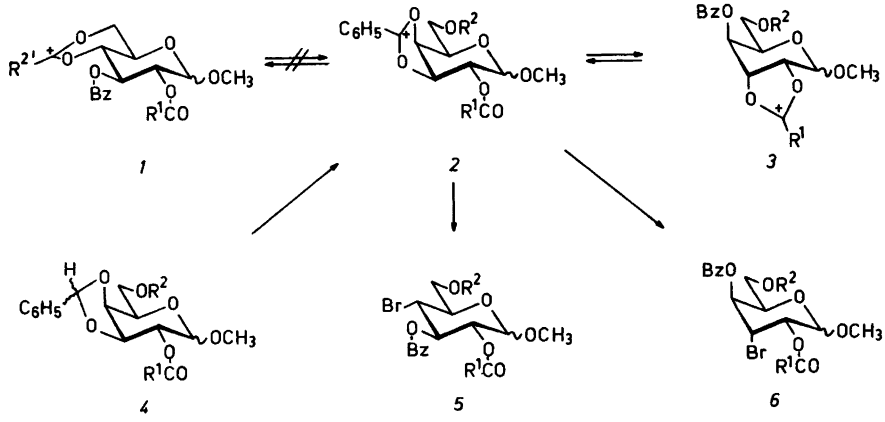
Table 2. ^{13}C Chemical shifts (δ-values) of benzoxonium ions in acetonitrile-d_3 solution.

Compound	C1	C2	C3	C4	C5	C6	C+
α2a	95.5	67.0	85.1	86.8	63.4	61.4	182.4
α2b	95.4	66.6[a]	84.8	85.9	63.5	66.5[a]	182.0
α2c	95.5	66.6	85.1	86.7	63.5	61.5	–
α3b	92.5	79.9	84.8	64.5	63.5	67.2	–
α3c	92.9	78.1	82.7	64.3	63.9	61.5	180.0
β2a	97.9	65.6	82.1	85.7	66.6	62.0	182.3
β2b	97.7	65.3	81.8	84.5	66.2	67.3	182.0
β2c	97.8	65.3	82.3	85.7	66.6	61.6	–
β3c	99.0	82.0[a]	84.2[a]	70.7[b]	69.9[b]	61.6	–

[a, b] Assignment may be reversed.

benzoxonium ion as possessing the galacto configuration, and allowing a complete assignment of the ^{13}C NMR spectrum (Table 2). Hydrolysis of the benzoxonium ion *β2a* followed by debenzoylation gave methyl β-D-galactopyranoside accompanied by a small amount (< 10 %) of the α-galactoside, resulting from anomerization. No evidence of rearrangement due to neighbouring group participation from the 2- or 6-*O*-benzoyl groups was found. Reaction of the ion *β2a* with bromide ion gave solely methyl 2,4,6-tri-*O*-benzoyl-3-bromo-3-deoxy-β-D-gulopyranoside (*β6a*), produced by *trans* diaxial opening of the galactobenzoxonium ion.

In order to test whether neighbouring group participation of the acyl groups on O-2 and O-6 was observable at all, methyl 3,4-*O*-benzylidene-2,6-di-*O*-*p*-methoxybenzoyl-β-D-galactopyranoside (*β4c*) was treated with trityl fluoroborate in acetonitrile. A ^{13}C NMR spectrum on the reaction mixture revealed the presence of three benzoxonium ions: One (40 %) with a spectrum very similar to that of the β-galacto ions described above and therefore identified as *β2c*; a second ion (40 %), presumably the β-gulobenzoxonium ion *β3c*, and, finally the α-gulo ion (*α3c*) described below (20 %). The presence of *α3c* is attributed to anomerization under the acidic reaction conditions, probably due to a small amount of water entering the reaction mixture. Hydrolysis of the benzoxonium ion mixture followed by deacylation gave a mixture of methyl glycosides shown by ^{13}C NMR spectroscopy to contain 40 % of methyl β-D-galactopyranoside, 40 % of methyl β-D-gulopyranoside and 20 % of methyl α-D-gulopyranoside. On the basis of the 1:1 ratio between the β-gulo-*p*-methoxybenzoxonium ion (*β3c*) and the β-galactobenzoxonium ion (*β2c*) the



a: $R^1 = C_6H_5$; R^2 = Bz b: $R^1 = C_6H_5$; R^2 = Ts c: p-$CH_3OC_6H_5$; $R^2 = R^1CO$

content of the unsubstituted β-gulobenzoxonium ion (*β3a*) in equilibrium with the β-galactobenzoxonium ion (*β2a*) can be estimated to ≃2 %, assuming the same stabilizing effect of the *p*-methoxy substituent as has been found previously.[3] This quantity of *β3a* is well below what would have been detected by direct NMR-spectroscopic investigation of the equilibrium mixture. Reaction of the benzoxonium ion system *β2c*⇄ *β3c* with bromide ion gave solely methyl 4-*O*-benzoyl-3-bromo-3-deoxy-2,6-di-*O*-*p*-methoxybenzoyl-β-D-gulopyranoside (*β6c*) as a result of *trans* opening of the galacto ion *β2c*. This is in agreement with previous results,[3] indicating that the equilibration between the benzoxonium ions occurs faster than the reaction with bromide ion, allowing preferential attack on one ion, even when more ions are present.

A comparison between the results described here with those obtained from the equilibration of benzoxonium ions derived from 1,6-anhydro-β-D-galacto- and gulopyranoside having the $^1C_4$ conformation as compared to the $^4C_1$ conformation adopted by the methyl hexopyranosides, reveals that the conformation completely dominates the outcome of the reaction. The equilibrium between the gulo- and galactobenzoxonium ions strongly favours the gulo ion in the 1,6-anhydride case, wheras the galacto ion is favoured in the methyl glycoside case. When reacted with bromide ion the 1,6-anhydride is attacked preferentially on the gulo ion, the methyl glycoside, however, on the galacto ion. When the attack by bromide ion on the 1,6-anhydride is forced to take place on the galacto ion by blocking the rearrangement to the gulo ion, the galacto ion is attacked at C-4 rather than at C-3.

Treatment of methyl 2-*O*-benzoyl-3,4-*O*-benzylidene-6-*O*-tosyl-α-D-galactopyranoside (*α4b*) with trityl flouroborate in acetonitrile gave two benzoxonium ions, of which the major component (90 %) was identified as the galactobenzoxonium ion *α2b* by its ^1H NMR spectrum. A minor component (10 %) was present in amounts insufficient for ^1H NMR spectroscopic identification, but was identified as the gulobenzoxonium ion *α3a* from its ^{13}C NMR spectrum, which closely resembles the spectrum of the gulo ion *α3c* described below. Addition of bromide ion to the benzoxonium ion system *α2b*⇄*α3b* in acetonitrile gave two bromo-deoxy sugars in a ratio of 3:1. The major product was methyl 2,3-di-*O*-benzoyl-4-bromo-4-deoxy-6-*O*-tosyl-α-D-glucopyranoside (*α5b*) and the minor product methyl 2,4-di-*O*-benzoyl-3-bromo-3-deoxy-6-*O*-tosyl-α-D-gulopyranoside (*α6b*) both resulting from *trans*-opening of the galactobenzoxonium ion *α2b* by the bromide ion.

Oxidation of methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-α-D-galactopyranoside (*α4a*) with trityl fluoroborate gave a mixture of a galacto- and a gulobenzoxonium ion, *α2a* and *α3a* respectively, in a ratio of 8:1. The reaction mixture on examination by ^1H and ^{13}C NMR spectroscopy closely resembles that obtained from the 6-*O*-tosylate described above, and hydrolysis followed by deacylation gave methyl α-D-galactopyranoside (>90 %). Reaction of the benzoxonium ions with bromide ion gave two products in the ratio 2:1, the major product being methyl 2,3,6-tri-*O*-benzoyl-4-bromo-4-deoxy-α-D-glucopyranoside (*α5a*) as a result of *trans* diequatorial opening of the galacto ion *α2a*, the minor product methyl 2,4,6-tri-*O*-benzoyl-3-bromo-3-deoxy-α-D-gulopyranoside (*α6a*) as a result of *trans* diaxial opening of *α2a*. In order to shift the equilibrium sufficiently towards the gulo ion to allow its direct observation, methyl 3,4-*O*-benzylidene-2,6-di-*O*-*p*-methoxybenzoyl-α-D-galactopyranoside(*α4c*) was treated with trityl fluoroborate to give the galacto-gulobenzoxonium ion equilibrium *α2c*⇄ *α3c*, which now favoured the gulo ion by 6:1 as seen from the ^{13}C NMR spectrum.

When comparing the benzoxonium ions derived from α- and β-galactopyranosides it appears that the galacto-gulo equilibrium is shifted slightly towards the gulo ion in case of the α-anomer. This causes no change, however, in their reaction with bromide ion, both anomers being attacked solely on the galacto ion. 1,3-Diaxial interaction from the methoxy group at C-1 in the α-anomer causes the α-galacto ion preferentially to undergo diequatorial opening by attack at C-4, while the β-anomer exclusively undergoes *trans* diaxial opening by attack on C-3. A similar 1,3-diaxial interaction between methyl groups and an incoming nucleophile has been observed in the opening of benzoxonium ions derived from steroids with bromide ion.[4]

In addition to the rearrangement of galactobenzoxonium ions to gulobenzoxonium ions through neighbouring group participation from the acyloxy group on C-2, a rearrangement to a glucobenzoxonium ion (*1*) could be envisaged as a result of neighbouring group participation from the acyloxy group on C-6. No such dioxanylium ion could be detected, however, neither directly, even when favoured by the presence of a stabilizing 6-*O*-*p*-methoxybenzoyl group, nor indirectly through

attack by bromide ion leading to 4-bromogalactose or 6-bromoglucose derivatives.

EXPERIMENTAL

Thin-layer chromatography (TLC) was performed on silica gel PF_{254}(Merck); for preparative work 1 mm layers were used on 20 × 40 cm plates. Compounds were visualized by UV light. Melting points are uncorrected. Optical rotations were measured in chloroform solution on a Perkin-Elmer 141 instrument. ^1H NMR spectra were measured on Bruker HXE 90 and HX 270 instruments and ^{13}C NMR spectra on a Bruker WH 90 as previously recorded. All spectra were measured in deuteriochloroform unless otherwise specified.

Benzylidene derivatives

General procedure. The appropriate 6-*O*-acyl- or 2,6-di-*O*-acyl-D-galactoside was transacetalized with benzaldehyde dimethylacetal in analogy to the procedure described for methyl α-D-glucopyranoside.[5] If the products did not crystallize directly, they were extracted with chloroform, dried ($MgSO_4$), concentrated and purified by preparative TLC.

*Methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-α-D-galactopyranoside (α4a).* Methyl 2,6-di-*O*-benzoyl-α-D-galactopyranoside[6] (1.60 g) gave 1.41 g (73 %) of *α4a* as a sirupy, diastereomeric mixture. Anal. $C_{28}H_{26}O_8$: C, H. ^1H NMR: δ 6.29 and 5.98 (ArCH), 3.41 (OCH_3).

*Methyl 2-*O*-benzoyl-3,4-*O*-benzylidene-6-*O*-tosyl-α-D-galactopyranoside (α4b).* Methyl 6-*O*-tosyl-α-D-galactopyranoside[7] (1.23 g) on acid catalyzed transacetalization with benzaldehyde dimethylacetal gave a crude product, which was benzoylated with benzoyl chloride in pyridine and subjected to preparative TLC in ethyl acetate–pentane (2:1) to give 1.34 g (70 %) of *α4b* as a sirupy, diastereomeric mixture. Anal. $C_{28}H_{28}O_9S$: C, H, S.

*Methyl 3,4-*O*-benzylidene-2,6-di-*O*-p-methoxybenzoyl-α-D-galactopyranoside (α4c).* Methyl 3,4-*O*-isopropylidene-α-D-galactopyranoside[8] (4.70 g) was anisoylated with *p*-methoxybenzoyl chloride in pyridine to give 7.60 g (75 %) of methyl 3,4-*O*-isopropylidene-2,6-di-*O*-*p*-methoxybenzoyl-α-D-galactopyranoside (*7*), m.p. 128–129 °C (from ethanol), $[\alpha]_D^{25}$ +97° (*c* 1.5), anal. $C_{26}H_{30}O_{10}$: C, H. Treatment of *7* (6.75 g) with acetic acid (75 %, 75 ml) at 100 °C for 1 h, evaporation to dryness, solution in chloroform, neutralization with aqueous $NaHCO_3$, drying ($MgSO_4$) and concentration gave 5.36 g (86 %) of methyl 2,6-di-*O*-*p*-methoxy-benzoyl-α-D-galactopyranoside (*8*), m.p. 143–145 °C (from ethanol), $[\alpha]_D^{25}$ +85° (*c* 1.2), anal. $C_{23}H_{26}O_{10}$: C, H. Transacetalization of *8* (2.27 g) gave 1.98 g (73 %) of *α4c* as a sirupy, diastereomeric mixture. Anal. $C_{30}H_{30}O_{10}$: C, H. ^1H NMR: δ 6.23 and 5.93 (ArCH), 3.83 and 3.37 (OCH_3).

*Methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-β-D-galactopyranoside (β4a).* Methyl 2,6-di-*O*-benzoyl-β-D-galactopyranoside[6] (3.38 g) gave a crude *β4a*, which was crystallized from ether and recrystallized from ethyl acetate–pentane to give 2.55 g (62 %) of *β4a* as a diastereomeric mixture, m.p. 93–97 °C. Further recrystallizations gave an analytical sample, m.p. 95–97 °C, which was still a mixture of diastereomers. Anal. $C_{28}H_{26}O_8$: C, H. ^1H NMR: δ 6.28 and 5.91 (ArCH), 3.47 and 3.45 (OCH_3).

*Methyl 2-*O*-benzoyl-3,4-*O*-benzylidene-6-*O*-tosyl-β-D-galactopyranoside (β4b).* Methyl 3,4-*O*-isopropylidene-6-*O*-tosyl-β-D-galactopyranoside[9] (2.70 g) was benzoylated with benzoyl chloride in pyridine to give 3.04 g (89 %) of methyl 2-*O*-benzoyl-3,4-*O*-isopropylidene-6-*O*-tosyl-β-D-galactopyranoside (*9*) m.p. 147–148 °C (from ethanol), $[\alpha]_D^{25}$ +14.5° (*c*1.0). Anal. $C_{24}H_{28}O_9S$: C, H, S. ^1H NMR: δ1.28 and 1.52 ($(CH_3)_2C$), 2.43 ($ArCH_3$), 3.40 (OCH_3). Hydrolysis of *9* (3.40 g) with aqueous acetic acid (75 %, 30 ml) at 100 °C for 40 min gave, after evaporation and crystallization from chloroform–pentane, 2.70 g (75 %) of methyl 2-*O*-benzoyl-6-*O*-tosyl-β-D-galactopyranoside (*10*), m.p. 134–135 °C, $[\alpha]_D^{25}$ −26.3° (*c* 1.1). Anal. $C_{21}H_{24}O_9S$: C, H, S. ^1H NMR: δ 2.42 ($ArCH_3$), 3.43 (OCH_3). Conversion of *10* (1.35 g) into the benzylidene compound gave a crude product, which could be crystallized from chloroform to give 1.27 g (86 %) of *β4b*, m.p. 125–131 °C. Preparative TLC in ethyl acetate–pentane (1:1) gave (*R*)-*β4b*, m.p. 159–160 °C (from ethanol), $[\alpha]_D^{25}$ +40° (*c* 0.6). Anal. $C_{28}H_{28}O_9S$: C, H, S, ^1H NMR: δ 4.46 (H1), 5.26 (H2), 4.63 (H3), 4.3–4.0 (H4, H5, H6), 6.13 (ArCH), 3.47 (OCH_3), 2.41 ($ArCH_3$); J_{12} = 7.5 Hz, J_{23} = 7.0, J_{34} = 5.5, followed by (*S*)-*β4b*, m.p. 151–152 °C (from ethanol), $[\alpha]_D^{25}$ +39° (*c* 1.0). Anal: C, H, S, ^1H NMR: δ 4.49 (H1), 5.18 (H2), 4.49 (H3), 4.3–4.1 (H4, H5, H6), 5.77 (ArCH), 3.41 (OCH_3), 2.37 ($ArCH_3$); J_{12} = 7.0 Hz, J_{23} = 6.0, J_{34} = 6.0.

*Methyl 3,4-*O*-benzylidene-2,6-di-*O*-p-methoxybenzoyl-β-D-galactopyranoside (β4c).* Methyl 3,4-*O*-isopropylidene-β-D-galactopyranoside[9] (4.70 g) was anisoylated with *p*-methoxybenzoyl chloride in pyridine to give 6.9 g (71 %) of methyl 3,4-*O*-isopropylidene-2,6-di-*O*-*p*-methoxybenzoyl-β-D-galactopyranoside (*11*), m.p. 136–138 °C. Recrystallization from ethanol gave m.p. 139–140 °C, $[\alpha]_D^{25}$ +22° (*c* 1.2). Anal. $C_{26}H_{30}O_{10}$: C, H. Reflux of *11* (6.5 g) with aqueous acetic acid (75 %) for 1 h, evaporation to dryness, and crystallization from ethanol gave 5.0 g (80 %) of methyl 2,6-di-*O*-*p*-methoxybenzoyl-β-D-galactopyranoside (*12*), m.p.

149–151 °C, $[\alpha]_D^{25}$ −9.1 ° (*c* 1.1), anal. $C_{23}H_{26}O_{10}$: C, H. Conversion of *12* (2.54 g) to the benzylidene compound, which crystallized from ether, gave 0.69 g (25 %) of methyl 3,4-*O*-benzylidene-2,6-di-*O*-*p*-methoxybenzoyl-*β*-D-galactopyranoside (*β4c*) as a diastereomeric mixture, m.p. 148–149 °C. Several crystallizations from ethyl acetate–pentane and ethanol gave the pure (*R*)-*β4c*, m.p. 152–154 °C, $[\alpha]_D^{25}$ +21 ° (*c* 1.0). Anal. $C_{30}H_{30}O_{10}$: C, H.

Reaction of benzoxonium ions with bromide ion

General procedure. The benzylidene compound (≃ 500 mg) was treated with a 25 % molar excess of trityl fluoroborate in acetonitrile (10 ml) for 16 h. A 3-fold molar excess of tetraethylammonium bromide (dried over P_2O_5) was added and the solution stirred at room temperature for 2 h. The reaction mixture was worked up by stirring with aqueous $NaHCO_3$ for 10 min followed by extraction with chloroform to give the crude reaction product, which was separated on preparative TLC to give triphenylmethane and triphenylcarbinol moving with the solvent front, followed by the bromo-deoxy compounds. As the slowest-moving fraction a small amount of the hydroxy-benzoates was usually isolated, resulting from direct hydrolysis of the benzoxonium ions. The properties and yields of the individual bromo-deoxy-hexopyranosides are given below in order of elution on preparative TLC under the heading of the benzylidene compound, from which they were prepared.

*Methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-α-*D*-galactopyranoside* (α4a, 578 mg) gave a reaction mixture which was separated by preparative TLC (diethyl ether-pentane, 2:1) to give 123 mg (18 %) of impure methyl 2,4,6-tri-*O*-benzoyl-3-bromo-3-deoxy-α-D-gulopyranoside (*α6a*). Reflux for 1 h with 75 % aqueous acetic acid to remove a small amount of unreacted starting material, followed by re-chromatography gave a slightly impure sample of *α8a*, sirup, anal. $C_{28}H_{25}BrO_8$: C, H (Found Br 13.53 Calc. Br 14.04), ^{1}H NMR: *δ* 5.24 (H1), 5.55 (H2), 4.70 (H3), 5.70 (H4), 5.05 (H5), 4.5–4.6 (H6); J_{12} = 4.5 Hz, J_{23} = 4.5, J_{34} = 3.1, J_{45} < 1. The second compound, 256 mg (38 %), was methyl 2,3,6-tri-*O*-benzoyl-4-bromo-4-deoxy-α-D-glucopyranoside (*α5a*), sirup, $[\alpha]_D^{25}$ +113 ° (*c* 0.4), anal. $C_{28}H_{25}BrO_8$: C, H, Br. ^{1}H NMR (270 MHz): *δ* 5.23 (H1), 5.19 (H2), 6.12 (H3), 4.22 (H4), 4.41 (H5), 4.87 (H6), 4.73 (H6′), 3.46 (OCH_3); J_{12} = 3.6 Hz, J_{23} = 10.0, J_{34} = 10.2, J_{45} = 10.6, J_{56} = 2.1, $J_{56'}$ = 4.7, $J_{66'}$ = 12.3. The slowest-moving compound 155 mg (26 %) was the hydrolysis product, methyl 2,3,6-tri-O-benzoyl-α-D-galactopyranoside, identified only from its ^{1}H NMR spectrum: *δ* 5.21 (H1), 5.42 (H2), 4.6 (H3), 5.84 (H4), 4.5 (H5, H6), 3.44 (OCH_3); J_{12} = 3.7 Hz, J_{23} = 10.2, J_{34} = 3.5, J_{45} < 1.

*Methyl 2-*O*-benzoyl-3,4-*O*-benzylidene-6-*O*-tosyl-α-*D*-galactopyranoside* (α4b, 700 mg) gave a crude product, which on preparative TLC (diethyl ether-pentane, 2:1) yielded two fractions. The fastest-moving fraction consisted of two compounds and trace amounts of the starting material, and was crystallized from ethyl acetate–pentane to give 190 mg (24 %) of methyl 2,3-di-*O*-benzoyl-4-bromo-4-deoxy-6-*O*-tosyl-α-D-glucopyranoside (*α5b*), m.p. 125–126 °C, $[\alpha]_D^{25}$ +110 ° (*c* 1.4). Anal. $C_{28}H_{27}BrO_9S$: C, H, Br, S. ^{1}H NMR (270 MHz): *δ* 5.11 (H1), 5.02 (H2), 6.00 (H3), 4.07 (H4), 3.17 (H5), 4.45 (H6, H6′), 3.38 (OCH_3), 2.46 ($ArCH_3$); J_{12} = 3.7 Hz, J_{23} = 10.0, J_{34} = 10.2, J_{45} = 10.4, J_{56} = $J_{56'}$ ≃ 3. Concentration of the mother liquors, reflux for 1 h with 75 % aqueous acetic acid and re-chromatography gave a further 70 mg (9 %) of *α5b* and 85 mg (11 %) of methyl 2,4-di-*O*-benzoyl-3-bromo-3-deoxy-6-*O*-tosyl-α-D-gulopyranoside (*α6b*), sirup, $[\alpha]_D^{25}$ +87 ° (*c* 0.8). Anal. $C_{28}H_{27}BrO_9S$: C, H, Br, S. ^{1}H NMR (270 MHz): *δ*5.25 (H1), 5.53 (H2), 4.74 (H3), 5.60 (H4), 5.02 (H5), 4.41 (H6), 4.28 (H6′), 3.43 (OCH_3), 2.32 ($ArCH_3$); J_{12} = 4.2 Hz, J_{23} = 4.9, J_{34} = 2.8, J_{45} < 1, J_{56} = 7.0, $J_{56'}$ = 5.6, $J_{66'}$ = 10.4. The slow–moving fraction was the hydrolysis product, methyl 2,4-di-*O*-benzoyl-6-*O*-tosyl-α-D-galactopyranoside, 103 mg (14 %), m.p. 160–161 °C, $[\alpha]_D^{25}$ +121 ° (*c* 0.9). Anal. $C_{28}H_{28}O_{10}S$: C, H, S. ^{1}H NMR: *δ* 5.15 (H1), 5.37 (H2), 4.38 (H3), 5.67 (H4), 4.2–4.3 (H5, H6), 3.42 (OCH_3), 2.38 ($ArCH_3$); J_{12} = 3.6 Hz, J_{23} = 10.2, J_{34} = 3.4, J_{45} < 1.

*Methyl 2,6-di-*O*-benzoyl-3,4-*O*-benzylidene-β-*D*-galactopyranoside* (*β*4a, 500 mg) gave a crude product, which on preparative TLC gave 358 mg (58 %) of methyl 2,4,6-tri-*O*-benzoyl-3-bromo-3-deoxy-*β*-D-gulopyranoside (*β6a*), sirup, $[\alpha]_D^{25}$ +27.9 ° (*c*. 1.2). Anal. $C_{28}H_{25}BrO_8$: C, H, Br. ^{1}H NMR (270 MHz): *δ* 5.05 (H1), 5.30 (H2), 4.87 (H3), 5.62 (H4), 4.91 (H5), 4.66 (H6), 4.48 (H6′) 3.58 (OCH_3); J_{12} = 7.5 Hz, J_{23} = 3.8, J_{34} = 3.5, J_{45} = 1.2, J_{56} = 6.8, $J_{56'}$ = 6.3, $J_{66'}$ = 11.4. A second fraction, 60 mg, presumably a mixture of the hydrolysis products, methyl *β*-D-galacto-pyranoside 2,3,6- and 2,4,6-tri-benzoates, was isolated.

An authentic sample of *β6a* was prepared by benzoylation of methyl 4-*O*-benzoyl-3-bromo-3-deoxy-*β*-D-gulopyranoside[10] with benzoyl chloride in pyridine to give *β6a*, sirup, $[a]_D^{25}$ +28.6 ° (*c* 1.2), ^{1}H NMR identical with the product described above.

*Methyl 3,4-*O*-benzylidene-2,6-di-*O*-p-methoxybenzoyl-β-*D*-galactopyranoside* (*β*4c, 588 mg) gave a crude product, which on preparative TLC (ethyl acetate–pentane, 1:1) gave 319 mg (54 %) of methyl 4-*O*-benzoyl-3-bromo-3-deoxy-2,6-di-*O*-*p*-methoxybenzoyl-*β*-D-gulopyranoside (*β6c*), sirup,

$[\alpha]_D^{25}$ +26.1° (*c* 0.9). Anal. $C_{30}H_{29}BrO_{10}$: C, H, Br, ^{1}H NMR: δ 5.02 (H1), 4.29 (H2), 4.87 (H3), 5.63 (H4), 4.83 (H5), 4.64 (H6), 4.45 (H6'), 3.61 (OCH_3), 3.88 ($ArCH_3$); J_{12}=7.5 Hz, J_{23}=3.9, J_{34}=4.1, J_{45}=1.6, J_{56}=6.4, $J_{56'}$=7.0, $J_{66'}$=11.4, followed by 194 mg of a mixture of the hydrolysis products, which were not further purified.

Reaction of benzoxonium ions with water

General procedure. The benzoxonium ion was prepared as described above and hydrolyzed with aqueous $NaHCO_3$. After extraction with chloroform, drying and concentration, the product was deacylated with a catalytic amount of sodium methoxide in methanol overnight, neutralized with ion exchange resin (IR 120), concentrated, dissolved in water and extracted with chloroform. The water phase was concentrated and examined by ^{13}C NMR spectroscopy. The solutions obtained in this manner contained only methyl glycosides and the chemical shift agreed (±0.1 ppm) with previously published values.[11,12]

Authentic ^{13}C chemical shifts for methyl β-D-gulopyranoside were obtained in the following manner. To 1,6-anhydro-β-D-gulopyranose triacetate[3] (1.0 g) in dry nitromethane (30 ml) at 0 °C were added acetic anhydride (3.0 ml) and conc. sulfuric acid (0.3 ml), and the solution was stirred for 1 h at 0 °C. Addition of aqueous $NaHCO_3$ and extraction with chloroform gave crude α/β-D-gulopyranose pentaacetate, which was converted to 2,3,4,6-tetra-*O*-acetyl-α-D-gulopyranosyl bromide with hydrogen bromide in glacial acetic acid (30 %, 10 ml, 30 min). The crude bromide was stirred with silver carbonate (3.0 g) in methanol (50 ml) for 2 h, filtered and deacylated with sodium methoxide in methanol overnight. Neutralization with ion exchange resin (mixed bed) and concentration gave methyl β-D-gulopyranoside, 363 mg (54 %) as a glass. ^{13}C NMR (D_2O): δ 102.6 (C1), 74.9, 72.3, 70.5, 69.1 (C2, C3, C4, C5), 62.1 (C6), 58.1 (OCH_3).

Acknowledgements. Microanalyses were performed by Novo Microanalytical Laboratory. The pulsed Fourier spectrometers were provided by the Danish Natural Science Research Council.

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Received November 7, 1980.